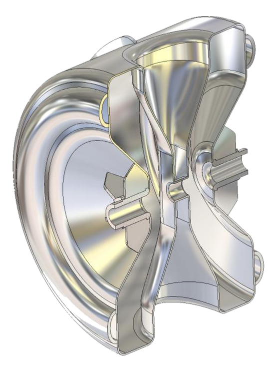
LLRF Design for the HINS-SRF Test Facility at Fermilab *

J. Branlard◊, B. Chase, E. Cullerton, P. Joireman, V. Tupikov

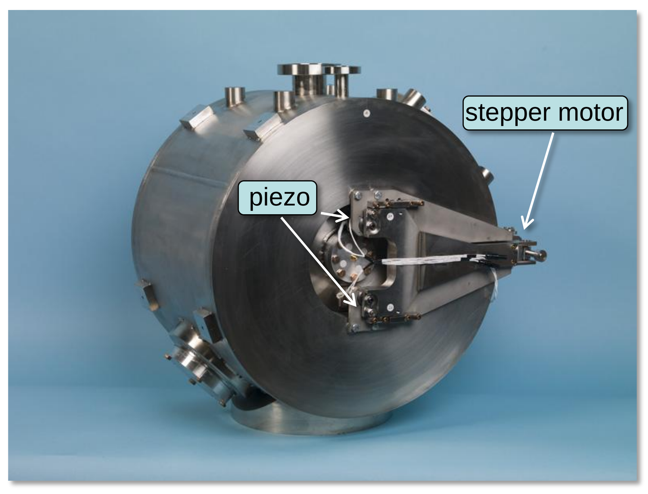
FNAL, Batavia IL, 60510, U.S.A

MOP 083

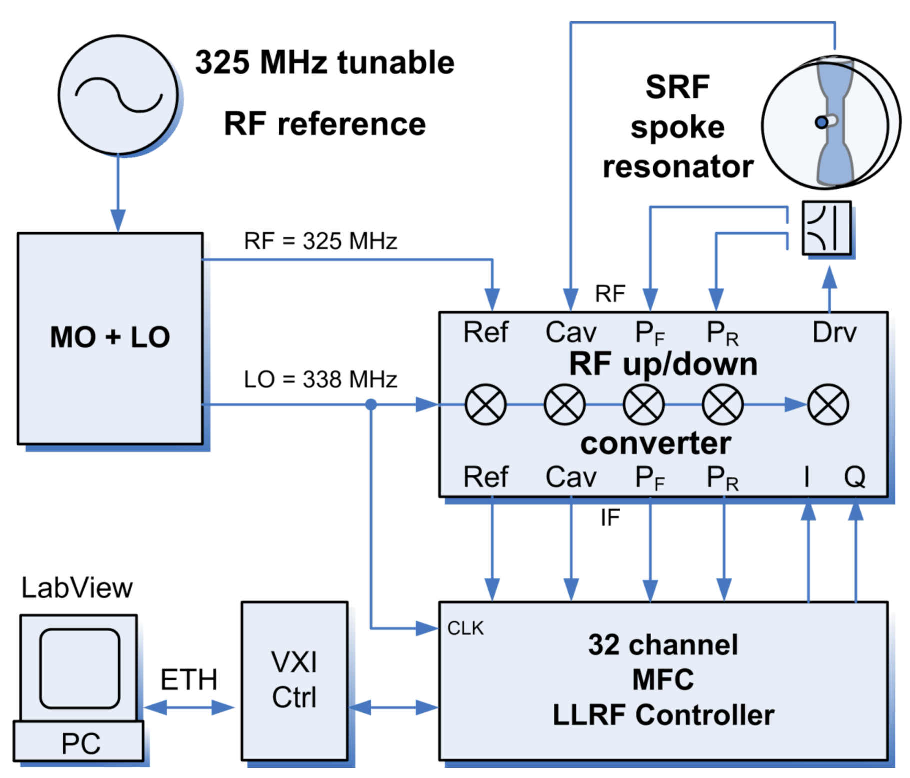
SSR1 cavity



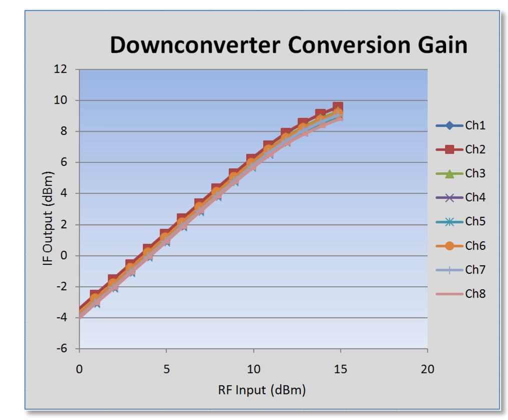
- Single Spoke Resonator
- RF = 325 MHz
- slow tuner (~ 200 kHz)
- 2 piezo tuners (~ 4kHz)



LLRF System Overview



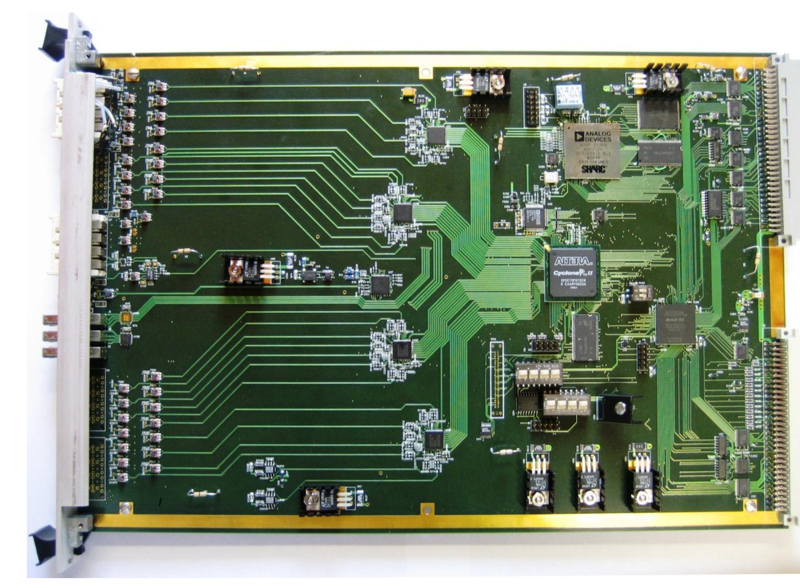
8 ch. receiver / 1 ch. transmitter



- RF: **325 MHz**
- LO: **338 MHz** (+6 dBm)
- Output 1dB compression point: **+13 dBm**
- Conversion loss: **-4 dB**
- Channel to channel isolation: **<-80 dB**
- Down converter output noise: **-163 dBc/√Hz** of ADC FS
- Transmitter output noise: **-148 dBc/√Hz** at 325 MHz

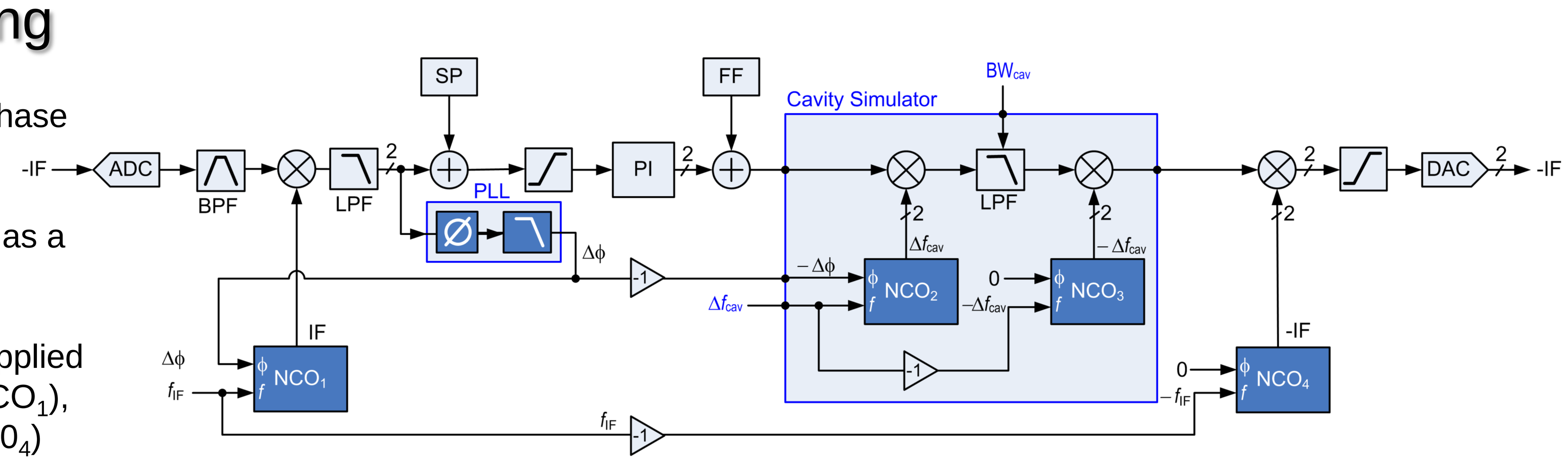
Multi Cavity field Controller

- IF: 13 MHz
- f_{clk}: 56.33 MHz
- 32x 12-bit ADCs
- 4x 14 bit DACs
- Cyclone II FPGA
- SHARC DSP



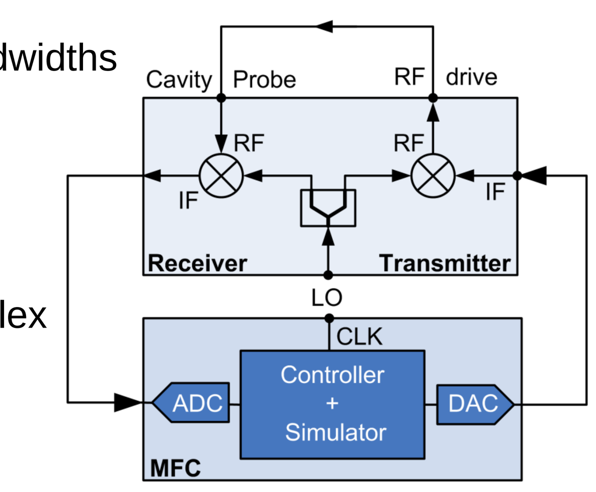
Frequency Tracking

- PLL with **CORDIC** detects phase of base band cavity signal
- NCO integrates phase error as a **frequency shift**
- The PLL correction is only applied at **downconversion** stage (NCO_1), not at upconversion stage ($NC0_4$)

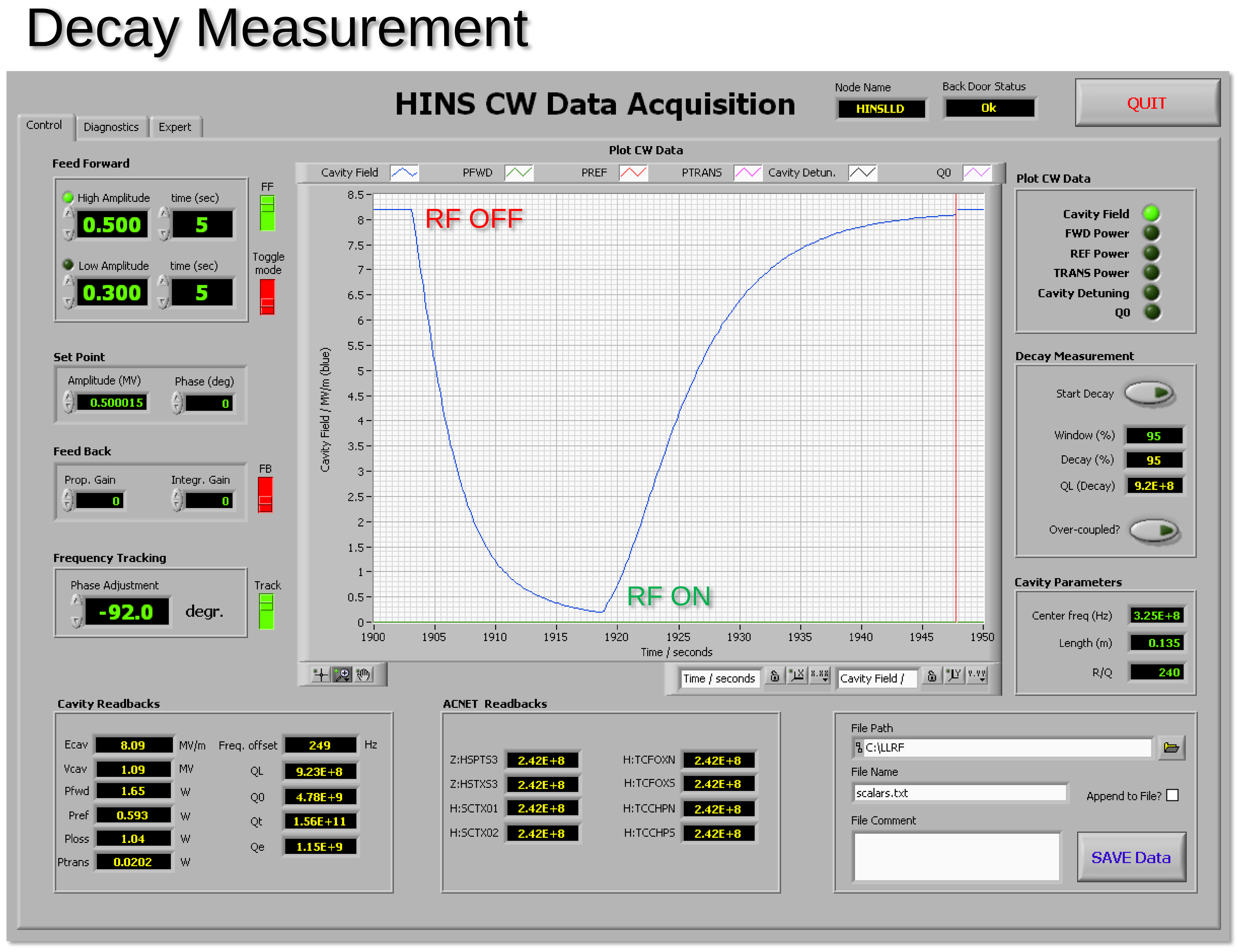


Cavity Simulator

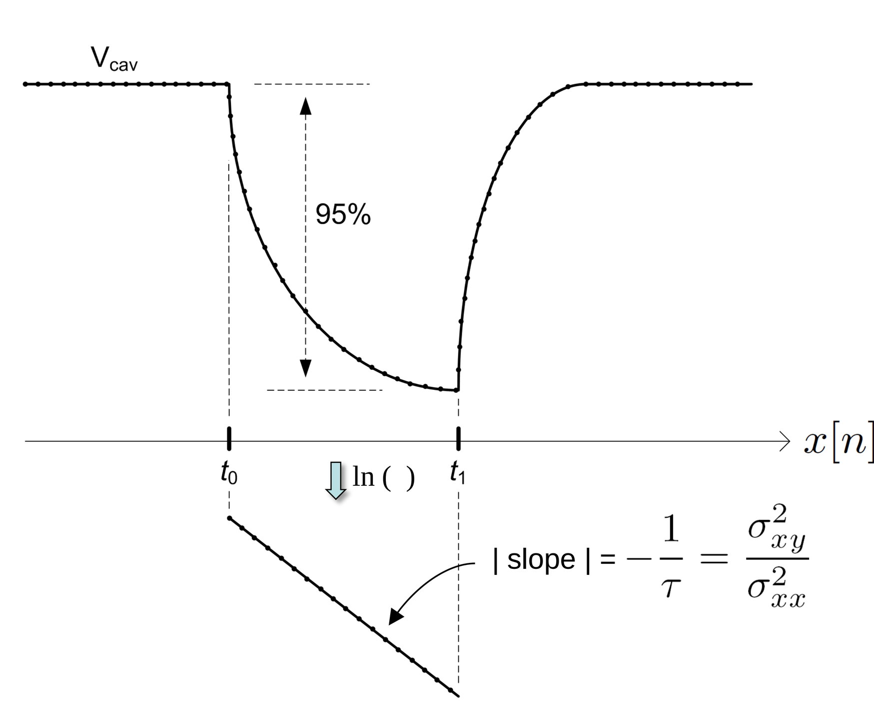
- cavities with 0.1 Hz to 10 kHz bandwidths
- Q_0 ~ 10^8 - 10^{10}
- direct BPF implementation "too expensive" in FPGA multipliers
- Instead, LPF in series with 2 complex multipliers
- **BW_{cav}** gives cavity 3dB passband
- **Δf_{cav}** gives cavity detuning



Decay Measurement



Q_L calculation from cavity probe decay



$$y[n] = \ln(V_{\mathrm{cav}}[n])$$

Compute means, variance and covariance:

$$\bar{x} = \frac{1}{N}\sum_{n=1}^{N} x[n] \qquad \sigma_{xx}^2 = \frac{1}{N}\sum_{n=1}^{N}(x[n]-\bar{x})^2$$

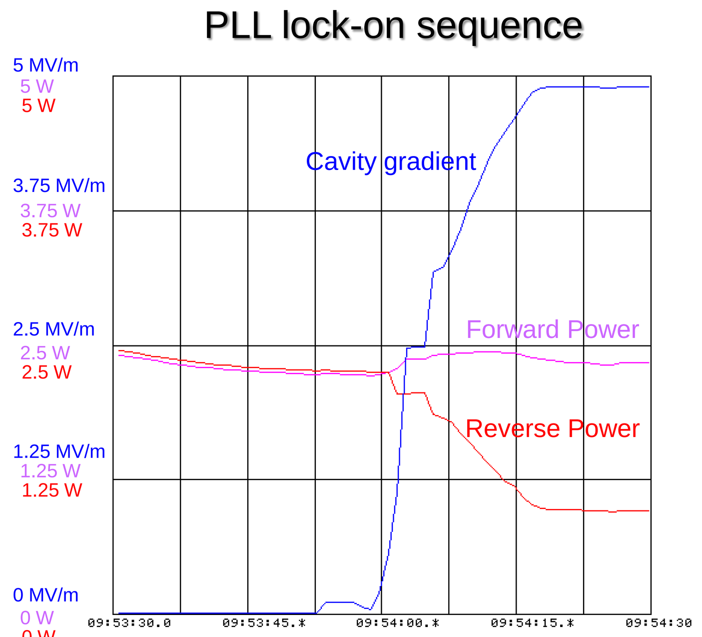
$$\bar{y} = \frac{1}{N}\sum_{n=1}^{N} y[n] \qquad \sigma_{xy}^2 = \frac{1}{N}\sum_{n=1}^{N}(x[n]-\bar{x})(y[n]-\bar{y})$$

1. Take natural log of cavity voltage
2. Compute averages, variance and covariance
3. Find least square linear fit
4. From the slope, compute Q_L

$$Q_L = \frac{\omega_0 \tau}{2} = -\frac{\omega_0}{2} \times \frac{\sigma_{xx}^2}{\sigma_{xy}^2}$$

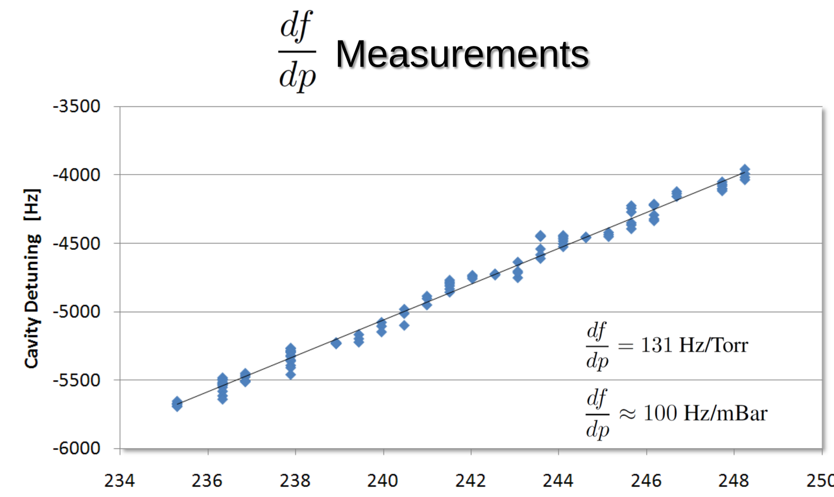
Results ‡

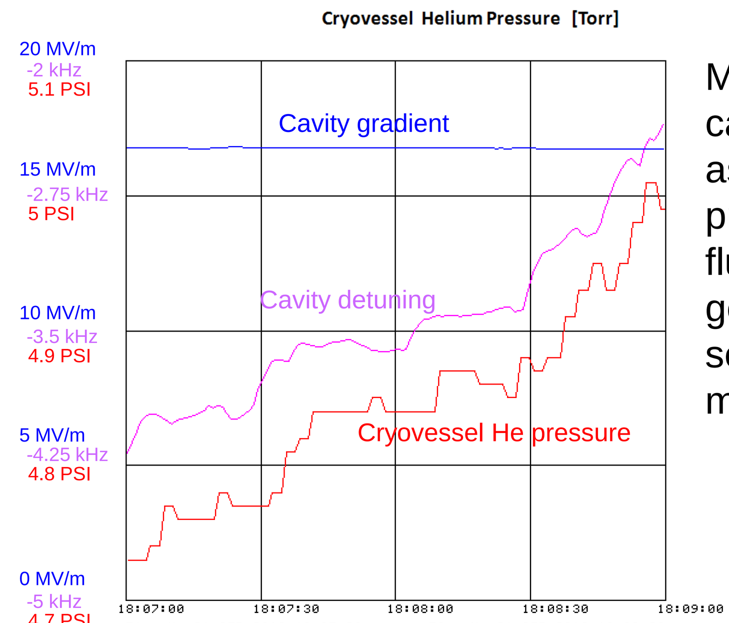
PLL lock-on sequence



When the PLL locks, the RF frequency matches the resonance frequency of the cavity. The reflected power drops, the cavity field increases.

$\frac{df}{dp}$ Measurements





Measuring the cavity detuning as a function of pressure fluctuations to get the cavity sensitivity to microphonics.

‡ see poster **THP031** for complete measurement results: "*First High Gradient Test Results of a 325 MHz Superconducting Single Spoke Resonator with Helium vessel at Fermilab*", R. Webber et al.

Real Time Measurements

1. During the decay, compute Q_L
2. From Q_L compute the following parameters:

$$Q_e = \frac{2Q_L}{1+\sqrt{\frac{P_R}{P_F}}}$$

$$Q_t = \frac{2Q_L}{1+\sqrt{\frac{P_R}{P_F}}} \times \frac{2P_F - P_R}{P_T}$$

$$Q_0 = \left(\frac{1}{Q_L} - \frac{1}{Q_e} - \frac{1}{Q_t}\right)^{-1}$$

$$P_{\mathrm{loss}} = P_F - P_R - P_T$$

$$V_{\mathrm{cav}} = \sqrt{R/Q \times P_{\mathrm{loss}} Q_0}$$

$$k_T = \frac{V_{\mathrm{cav}}}{\sqrt{P_T}}$$

3. Assuming k_T, Q_e and Q_t are constant
4. Compute real time values of V_{cav}, Q_0 and Q_L as follows:

$$V_{\mathrm{cav}} = k_T\sqrt{P_T}$$

$$Q_0 = \frac{V_{\mathrm{cav}}^2}{R/Q \times P_{\mathrm{loss}}}$$

$$Q_L = \left(\frac{1}{Q_0} + \frac{1}{Q_e} + \frac{1}{Q_t}\right)^{-1}$$

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LINAC10
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◊ branlard@fnal.gov